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This report results from a contract tasking Leninetz Holding Company, NIPGS as follows: Methods of research influence on shock wave formation can become a basis for creating highly effective, without inertia methods of management of the aerodynamic characteristics of flying devices. Use of energetically favorable methods of artificial plasma formations creation could lead to drag reduction, suppression of sound barrier, and to reduce undesirable sound influence. The research of electrophysical representation of processes in high-temperature reactor (HTR) represents the large interest for diagnostics and development of new types HTR, and could lead to opportunities of noise decrease. At the same time measurements of electrophysical parameters (potential and current density) allow the organizing of a feedback for correction of parameters of work HTR in the appropriate mode. The experimental data on the mutual influence (including its influence on noise) of these phenomena will be the subject of the first part of this project. The second part will be devoted to study shock waves formation in weakly ionized plasma.

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ISTC 2416

**Final**
**Project Technical Report**
**of ISTC 2416**

**Experimental and Theoretical Research on Concatenation of Acoustic and Shock Waves Parameters on Low-Temperature Plasma at Inside Combustion Flow**

**(From 1 July 2002 to 31 December 2004 for 30 months)**

**Alexander Leonidovich Kuranov**
**(Project Manager)**
**"Hypersonic Systems Research Institute" Joint Stock Company**

**December 2004**

ISTC 2416

Fundamental and applied research have been conducted in the sphere of plasma gasdynamics, processes in combustion yields plasma and the works have been performed on creation and testing of a new type plasma generator  for the control over aerodynamic performance of flight vehicles.

**(From 1 July 2002 to 31 December 2004 for 30 months)**

**Alexander Leonidovich Kuranov**
**(Project Manager)**
**"Hypersonic Systems Research Institute" Joint Stock Company***

The objective of this project is to carry out fundamental and applied research in the sphere of plasma gasdynamics and the processes in combustion yields plasma. Development, manufacture and gasdynamic tests of plasma generator of a new type for control of aerodynamic performance of flight vehicles. Development, creation and bench tests of the new diagnostic methods of the processes in high temperature reactors with application of electrophysical characteristics of combustion yields plasma.

Keywords: plasma gasdynamics, electrophysical characteristics, new diagnostic methods, plasma generator

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# CHAPTER I

## "THE ELECTROPHYSICAL PHENOMENA IN PLASMA OF COMBUSTION PRODUCTS OF A HIGH-TEMPERATURE REACTOR AND THEIR CONNECTION WITH SHOCK AND ACOUSTIC WAVE PROPAGATION AND ENGINE NOISE"

**Statement of a problem**

The works which are carried out within the framework of this project are directed at the improvement of characteristics and enhancement of operational safety of supersonic aircraft and prospective hypersonic flight vehicles. Solution technologies of the problems under consideration herein are associated with plasma. The plasma phenomena play an essential role in engines. The status of the above problem and substantiation of the necessity for the new diagnostic methods are discussed below.

### 1.1. Problems of operating reliability enhancement

The problems and basic trends of development of the air-and space-rocket transport systems, first of all, are determined by the demands for substantial performance improvement of the heat engines and energy converters of various designations. The engine properties improvement, enhancement of their general and operational reliability stipulate for possibilities of increasing technical and economic efficiency of the air-and space-rocket transportation systems and can be realized, in their turn, only on the basis of continuous development of fundamental scientific, engineering and technological research.

Improvement of engine operating reliability will result in cost reduction for creation and operation of space technology facilities and ensure actual elimination of the carriers loss caused by the engine-related emergencies.

It should be noted, however, that provision of engine reliability parameters by traditional ways and means nowadays is rather difficult, if not impossible. There is an opinion, for example, that solution of a number of space problems is possible if failure-free engine operation probability is $\geq 0.999$, i.e., when required level of the unfailing operation of a single engine will be $\geq 0.9999$.

Thus, required levels of operational reliability of aero-and-space-rocket transportation systems can be ensured only by all-embracing measures. These measures, along with hot redundancy of the engines, stipulate for possibilities to improve their operating conditions, their equipment with highly efficient systems of diagnostics and emergency protection, as well as increase of physical reliability of the aggregates they are composed of.

Thus, the problem of ensuring the required levels of the engines operating reliability is of a complex (systematic) character. It presupposes the following:

* the necessity to elaborate the initial theoretical postulates and design methods,
* the necessity to introduce corrections into existing practice of experimental development and operation of the heat engines,
* perfection of the methods of providing the necessary levels of survivability and reliability of the engines.

The above problem can be solved only on the background of a qualitative leap in the propulsion engineering development as a whole.

From the viewpoint of technical diagnostics objectives, it is HTR' physical state and quality of the working process realized in its volume that determines jointly unified diagnostic system.

Naturally, diagnostic process of the specific system should take into consideration mutual stipulation of the states of its separate components, when physical state of the chamber, under other necessary conditions, determines directly signs of quality of the in-chamber process and, in its turn, is characterized by them. Thus, quality signs of the working process are of a generalized nature jointly determining diagnosis both in respect to the physical state of the chamber, and to the quality of the working process. The above points out that it is expedient to orient technical diagnostics of HE chamber toward the usage of diagnostic signs directly characterizing quality of its working process.

It is believed, for instance, that pulsation component of pressure in the heat engine chamber, simultaneously with the data on the stability of in-chamber process, reflects the chamber' physical state as well. In other words, pulsation component of the chamber pressure as a parameter (sign) is rich in diagnostic content both in relation to the quality of the working process and to the physical state (operability) of the engine as a whole (or to be more precise – of the chamber, as its most important aggregate).

Prospects of technical diagnostics systems development might be considerably improved at the expense of non-traditional measurement ways and means application that would expand diagnostic information. Certain advantages, in particular, could have diagnostic systems using analytical results of the process electro physical representations.

True, recording and subsequent analysis of its electro-physical representations, if compared with traditionally evaluated parameters, have some significant advantages as regards both methodical and equipment support. It can be practically performed by non-inertia methods with high resolving power the application of which in many cases do not require destruction of structural integrity of chambers and is not accompanied by the decrease of their reliability, do

not introduce any disturbances into the process under investigation and lifts all kinds of limitations as regards its frequency responses. Practical non-inertia inherent generally in electro-physical methods is a fundamental, if not the most important, factor of the successful solution of the basic problem of HE technical diagnostics and that is efficient detection of pre-emergency situations.

In other words, expediency of using information on electro-physical characteristics of the in-chamber processes for diagnostic purposes is dictated by the necessity to develop and enhance efficiency of diagnostic systems proper, as well as (by) prospects to increase reliability of engine's aggregates and expand our knowledge of the in-chamber processes, as a whole.

Within the frame of this work the following is stipulated:
- to identify principal features and base mechanism of electro-physical representations of the in-chamber process (its electro-acoustic pattern);
- to refine informative and diagnostic content of electro-physical information reflecting the HE working process;
- to substantiate application possibilities of the information on electro-physical representations of the working process for the engine diagnostics and the prospects of enhancement, on this basis, of their physical and operational reliability.

As applied to the problem of reliability enhancement for the air-and-space-rocket transportation systems, of a great importance is a quest of suppression measures for the processes of engine electrization. Accumulation of electric charges on the bodies/airframes of transport carriers (planes, rockets, space vehicles) is fraught with the whole complex of undesired phenomena.

It is believed now, that electrization promotes:
- increased explosion hazard for the fuel systems;
- increased probability of atmospheric electricity shock for transportation systems;
- growth of interference, disruption of radio equipment, means of control and communication functioning;
- deterioration of operation conditions for the instrumentation of the transportation systems, as well as power systems and solar-cell panels for the space flight vehicles.

As per existing ideas, there are at present two elictrization mechanisms that differ considerably: mechanism of external elictrization that is the result of interaction between flying vehicle and surrounding medium, and inherent in HE mechanism of internal (engine) electrification stipulated by carrying away (ablation) of combustion yields of electric charge into surrounding medium with outflow in the course of engine operation.

Despite the similarity of the end symptoms of the external and internal elictrization, the levels of the knowledge as regards their separate mechanisms substantially differ. While the problem of the aircraft external elictrization was closely studied for a long time, it is only recently that internal one attracted attention of the researchers.

According to the present day thinking, the form (appearance) of charges carried away into surrounding medium depends on HE type, the origin of the fuel and its components ratio, specific features of the engine's pneumohydraulic systems, etc. It is believed, that a significant contribution to the process of charge accumulation on the bodies/airframes of the air-and space-rocket transportation systems by the mechanisms of internal elictrization is made by:

- ionized products of combustion (for all types of fuels);
- solid particles, especially in combustion yields of the solid fuels at the expense of deceleration and friction mechanisms;
- small only partially burnt particles of the fuel;
- large size agglomerates formed as a result of smaller particles burning.

It is traditionally assumed that the most significant mechanism of the HE internal electrization is associated to the utmost degree with the charge carrying out (ablation) from the double electric layer being formed on the separation border of the media "the wall – combustion yields plasma". The computational models of the internal electrization process on the basis of such ideas are well-known. However, the above models are fabricated with quite a number of various assumptions and are, in essence, the empiric ones that to a very small degree reflect its mechanism which is rather complicated in respect of the character of the recorded symptoms.

The ideas of key contribution to the internal electrization mechanism of the current ablation from the double electric layer, supported by some authors, are not in full agreement with observation results, and what is more – they are in the obvious disagreement with general conception of the double electrical layer proper. The experiments show that the most typical polarity sign of the charge being carried out under high-temperature mode of HE operation is "+", while the negative (-) sign is inherent in the low-temperature mode of HE running. In other words, experimentally detected and theoretically evaluated signs of the charge for the foregoing modes of HE operation are exactly opposite.

Thus, it seems expedient that further elaboration of the internal electrization mechanism be conducted with orientation toward necessity of revelation of the most common features between characteristics of the working process in HE chambers, on the one part, and their electrophysical representations, on the other part. Such an approach determines a sensible direction of finding ways of efficiency enhancement for the systems of HE technical diagnostics and increase of operational reliability for the air-and space-rocket transportation systems on their basis.

It is well known, that basic conceptions on high-frequency [HF] instability of the processes in the chambers of the rocket engines have been formulated 35-40 years ago. But in general, the phenomenon of the in-chamber high-frequency instability up till now did not offer a proper interpretation.

So far, there is no unanimous opinion on the causes of HF instability origin, the sources and mechanisms of energy provision for accompanying its development HF-oscillations of pressure (especially their amplification, up to the dangerous - from the engine operability viewpoint - levels). Moreover, investigation results of the in-chamber HF instability obtained so far, show not only exceptional complexity of its mechanisms but also point out insufficient potentialities of HF instability research methods on the basis of generally accepted views.

The situation at hand makes it expedient to conduct also HF instability in-chamber investigations on the basis of non-traditional novel approaches that would take into account, first of all, plasma properties of the combustion products.

So, the working process in HE chambers is represented by complicated in character electro-physical symptoms (representations – EPR), formation mechanism of which, as well as information content, remains unclear so far and leaves much room for speculation.

It is but natural to assume that in the base of this mechanism lies, firstly, formation of irregularities in volumetric distribution of the charge in combustion yields medium (due to acoustic effects of the in-chamber parametric non-stationarities).

There are also reasons to suppose existence of bonds between parameters of acoustic effects and spatial time responses of the charge irregularities.

It should be noted, that the products of combustion in this case are up to the notion of thermodynamically open three-liquid plasma medium containing neutral, ionic and electronic components. The local medium composition will be determined by the values of ionization degree.

At the first stage of the work it is necessary to clearly demonstrate how variations of principal characteristics of the processes in HTR and in combustion yields plasma affect electrophysical representations. After that it will be safe to declare that we have a very reliable method of diagnostics that will enable further on to control and correct our quest for the methods of impact on the processes in HTR. Of a special interest is passage/propagation of acoustic and detonation waves and HF radiation through/into plasma of combustion yields. A three-liquid model can be used for mathematical modeling of the processes and more confident interpretation of experimental results. We shall demonstrate "reaction" of electro-physical representations on the essential parameters of combustion (availability of easily ionized additives, accompanying

chemical reactions, propagation of detonation or acoustic wave) by experimental and theoretical methods.

The general status of the problem was taken into consideration when substantiating expedient directions of research on this problem as a whole. At this particular stage it is necessary to solve a number of rather complicated and principal issues:

- identify principal features and basic mechanism of formation of electro-physical representations of the process in the HE high-temperature reactors;
- elaborate informative and diagnostic content of electro-physical information, reflecting HE working process;
- prove experimentally potentialities of measurement and consequent application of specific information on electro-physical representations of the working process for diagnostic purposes.

With these objectives in mind, our efforts have been directed to the development and production of laboratory equipment required for the fulfillment of the above exploratory stage and conducting check experiments to verify serviceability of the equipment.

## I.2. The equipment and experiment procedures

The bench installation for realization of the experimental part of investigations is based on the model high-temperature reactors and contains the following principal aggregates and systems:

1. A model high-temperature reactor [HTR] designed for usage of various fuels and taking measurements of hydrodynamic, electro physical and other parameters under high pressures in the chamber, various ratios of fuel components and spectral response characteristics of in-chamber instability;
2. Reactor fuel component supply system;
3. Management and control characteristics systems of the reactor mode;
4. Information recording, processing and analysis systems.

HTR fuel systems have to provide for ability to effect on combustion yields medium by a high steepness detonation wave front. The medium conductivity measurement is stipulated by means of

diverse sensors including the following:

- contour sensors capable of variation of tuned-circuit Q-factor (they have different dimensions, various localities and can determine electro-physical media characteristics in diverse volumes);
- local electrode probe-type sensors powered by both impulse supply and constant voltage.

The above systems are fitted with special means for sensor calibration and analysis of the results obtained.

The high-temperature reactor (HTR) with the above design and performance has been used.

The electric-and pneumohydraulic systems of the test stand were providing for the supply of fuel and auxiliary elements into HTR and a number of additional aggregates of the installation. The stand was equipped with remote control systems, necessary instrumentation, the external magnetic field system.

Depending on specific objectives of the experiment, the stand ensures HTR usage either as separately operating aggregate or jointly with MHD channel of a measuring-type.

In the course of experiments, apart from electro-physical parameters, recording of the HTR and MHD-channel performance is stipulated. Aviation kerosene T1 was used as a fuel and the air served as oxidizer.

The MHD channel was intended for usage when investigating conductivity of combustion yields (kerosene +air). At the design stage, the channel with segmented electrodes (six segments lengthwise of the channel) has been taken as the initial one.

Considering relatively low temperature of the combustion products and limited time of the experiment, non-cooling structure of the channel was accepted as a principal one. The channel's section is rectangular-shaped, the length of the working channel is 160 mm. The electrodes are made of graphite material. The adiabatic walls material is quartz. The selection of the law of the channel's section size variation has been conditioned by the provision of lengthwise outflow condition, as well as technological considerations.

The microwave methods of measuring electro-physical properties of plasma parameters are based on the interaction of magnetic waves with free charge carriers in plasma and are in effect free of contact.

Let us consider some most generalized postulates that form the basis of measuring microwave procedures for investigation of ionized gaseous media, discussed at a great length in many publications.

Radio wave propagation into the ionized gas at the densities of charged species not lower $10^4$ cm$^{-3}$ (for the wavelength $\lambda \gg r$, $\tilde{a}\ddot{a}\mathring{a}\ r -$ , where r – average distance between species) can be investigated with the help of macroscopic Maxwell's equations. In case of harmonic electromagnetic field whose components vary as per the law $e^{-i\omega\tau}$ , the system looks like follows:

$$rot\vec{H} = \sigma\,\vec{E} - i\omega\,\varepsilon_a\,\vec{E} \ ,$$
(1)

$$rot\vec{E} = i\omega \mu_a \vec{H},$$ (2)

$$div\vec{H} = 0,$$ (3)

$$div\vec{E} = 0,$$ (4)

where $\vec{E}$ and $\vec{H}$ – strengths of electric and magnetic fields, $\omega$ - circular frequency, $\sigma$ - conductivity.

Applying to (2) operation *rot* and using (1) and identity

$$rot\ rot\ \vec{A} = -\Delta\vec{A} + grad\ div\ \vec{A},$$

we get

$$rot\ rot\vec{E} + \omega^2(\overline{D} + i\frac{\sigma\vec{E}}{\omega}) = \Delta\vec{E} - \omega^2(\vec{D} + i\frac{\sigma\vec{E}}{\omega}) - grad\ div\ \vec{E} = 0.$$ (5)

Introduced in consideration complex dielectric constant of the medium $\varepsilon_a' = \varepsilon_a + i\frac{\sigma}{\omega} = \varepsilon_a(1 + i\frac{\sigma}{\omega\varepsilon_a})$ in case of anisotropic medium presents tensor value

$$\varepsilon_{i,k}' = \varepsilon_{a_{i,k}} + i\frac{\sigma_{i,k}}{\omega\varepsilon_{a_{i,k}}}.$$

In the isotropy case (5) assumes the form

$$\Delta\vec{E} + \omega^2\varepsilon_a' - grad\ div\ \vec{E} = 0.$$ (6)

In a general case, when $\varepsilon_a'$ depends on all coordinates, simplification of the complicated equation (6) is not possible. In case of monochromatic waves propagation in the isotropic medium, the equation takes on the following form under normal drop:

$$\frac{d^2E_{x,y}}{dz^2} + \omega^2\varepsilon(\omega,z)E_{x,y} = 0.$$ (7)

Within the frame of the assumptions made, we have a right to ignore existence of the longitudinal waves. The equation solution looks as

$$E = E_0 e^{\pm i\omega\sqrt{\varepsilon'}z} e^{-i\omega\tau},$$ (8)

where signs correspond to the waves propagating at the direction of positive axis Z (sign -) and at the opposite direction (sign +).

As per the nomenclature accepted in the microwave diagnostics theory, complex dielectric constant may be presented in the following form:

$$\varepsilon' = \varepsilon_1 + i\frac{\sigma}{\omega} = (n - i\chi)^2 = \varepsilon_1 + i\varepsilon_2, \tag{9}$$

where $n$ and $\chi$ - material values. The solution takes on the following form:

$$E = E_0 e^{\pm i\omega n z \pm \omega \chi z} e^{-i\omega\tau}. \tag{10}$$

It can be seen that values $n$ and $\chi$ characterize medium's effect on properties and distribution pattern of electro-magnetic waves and can be interpreted as indexes of refraction and absorption.

The approach under development allows to further indicate that under condition

$$\omega = \sqrt{\frac{n_e e^2}{m_e \varepsilon_0}} = \omega_p,$$

where $\omega_p$ - plasma frequency proper, the index of refraction value $n$ transforms into zero, i.e. oscillation passage with given frequency stops. The cut-off occurs.

The value of electron concentration meeting the cut-off requirement for the given $\omega$, is called critical one and is determined by:

$$n_{e_{cr}} = \frac{m_e \omega^2 \varepsilon_0}{e^2}.$$

Different modifications of the method are based on the dependence of $n$ and $\chi$ on the frequency of collisions and electron concentration.

It should be noted that the above fragments of theory are justified for the cases of wave propagation in the isotropic medium. Under this work conditions, it is expedient to apply the microwave methods only for the purpose of contraction the area of possible levels of the expected concentrations of the charged species (or electric conductivity) in the media under investigation.

The most acceptable for this purpose is the method of microwave radiation. Under observance of the condition $d > C/\omega$ ($d$ – thickness of the layer under investigation, $\omega$ - frequency of the probing radiation), plasma diagnostics by this method is rather reliable. It can be carried out both on one, as well as several wave-lengths simultaneously.

The expediency of electrode methods application is determined, first of all, by the fact that they are actually the only acceptable ones when investigating electro-physical properties of the gaseous media in the magneto-hydro-dynamic (MHD) channels.

The basis of MHD channels operation is the D.C. or low-frequency A.C. flow. Medium conductivity measurement in the MHD channel working volume seems rather simple only at the

superficial consideration of this issue. There is a well-known procedure of conductivity determination by means of short circuit current, being measured in the course of the experiment, and potential difference of the "idle running" between MHD channel electrodes

$$\sigma = \frac{I \cdot l}{S_{y\ddot{e}} V_{xx}},$$

where $I$ – value of current flowing between electrodes in the short circuit mode; $S_{y\ddot{e}}$, $l$ – area of electrodes and the distance between them respectively; $V_{xx}$ – voltage on electrodes in the idle running mode. This method due to the symptoms of electrode-side phenomena in the system electrode – plasma – electrode allows one only approximate determination of the medium conductivity in the inter-electrode space.

The electrode-side phenomena in the system electrode – plasma – electrode result in that the existing value of electric intensity can turn considerably lower than one being calculated from relationship $E = V_{xx}/l$.

Potential distribution pattern in the inter-electrode plasma volume is determined not only by the plasma parameters and the voltage value on electrodes but electrode emissivity, too.

Dependence of emission current on electrode material, electrode surface temperature, electric intensity in plasma near the surface of electrode-emitter, results in that the distribution of the electric potential in the inter-electrode plasma volume, among other parameters, also depends on these values. And the non-linear effects manifest themselves not only in the cathode region of electric circuit but in the anode one, too.

At the MHD channel conditions, electric intensity in the non-disturbed plasma layers in the inter-electrode space, in accordance with

$$j = \sigma \{ E' - [\vec{u} \times \vec{B}] \}$$

can be provided for either at the expense of switching into electrode circuit of the external power source E' or owing to the interaction of the current with the magnetic field or jointly at the expense of both.

The manifestation of the non-linear effects in both cases results in that the effective electric intensity in the plasma non-disturbed layers could significantly differ from the value $E = V/l \neq E_{y\hat{o}}$ - in case of application to the electrodes $l$ distance away from each other, an external power source with voltage $V$ and at $B = 0$ or $E = uB \neq E_{y\hat{o}}$ - in case of short circuit at the absence of external source **and $B \neq 0$**.

In other words, to determine the value of plasma conductivity on the basis of Ohm's law, under MHD channel conditions, we need to have information on both the value of the inter-

electrode current and efficient electric intensity $E_{\acute{y}\hat{o}}$ in the non-disturbed plasma layers in the inter-electrode space.

The measurement system of the reaction products conductivity by the loop method has been used when investigating combustion yields of hydrocarbon fuels with both oxygen and air as oxidizer.

### 1.3. Experimental results

In Figs. 1 - 2 one can see the results of conductivity measurements for the combustion yields kerosene + air in the combustor space under pressures P = 0.4 MPa and 1.96 MPa.

When taking measurements, we have been introducing electrode sensors via special screw holes in the middle (cylindrical) part of the reactor. Figs. 1 and 2 data relate to the case where optimal version of HTR assembly was used: fuel injector' head was fitted with two-component jets of pre-chamber type, the cylindrical part of L 150 + 200 mm was used and no additional fuel injection via the probe was applied.

Curves I, II, III relate to the measurements in the sections 50, 100, and 150 mm away from the hot bottom respectively.

Diagrams also contain temperature mean values determined as per results of thermodynamic calculation with subsequent introduction of corrections on experimental values of pressure impulse. It is noteworthy, too, that absolute values of electric conductivity, fixed in each and every section, exceed equilibrium ones by more than an order.

The greatest deviation of the obtained electric conductivity values from equilibrium ones could be observed under oxidizer excess ratio which differ from optimal factor. Equilibrium values of electric conductivity have been estimated with allowance for availability in the fuel (kerosene) of maximum permissible rating of potassium natural admixture (up to $2 \cdot 10^{-5}$ %).

A notice is to be taken of the difference in the nature of temperature variations in the combustion yields and their electric conductivity lengthwise of the combustion chamber.

It would be expedient to assume, that combustion yields temperature if moving away from the hot bottom of the head, tends to increase monotonically (non-cooling combustor had been used), while maximum value of electric conductivity was registered in the second section. It points out, obviously, that in this particular case a degree of ionization and its distribution pattern are determined not only by the temperature but the mechanisms associated with combustion processes as well.

Measurement data prove that electric conductivity level of combustion yields "kerosene + air" increases with reduction of pressure in high-temperature reactor.

### 1.4. Conclusion

The results of investigation on feeding of a very steep shock wave (that could only be compared in size to the steepness of high-frequency oscillation front) indicate that under typical for HTR high-frequency oscillatory process conditions:

1. information concerning pressure and electric-and-physical properties of combustion yields of the fuels with rather high levels of ionization (ours is the case of easily-ionized additives introduced into the fuel's medium) enables us to judge on the nature and levels of temperature changes in HTR, as well as on local and mean-integral characteristics of the fuel burn-up, alterations of its composition;

2. information concerning pressure and electric-and-physical properties of combustion yields of the fuels with low levels of thermal ionization (clean-burning fuels) can be used for characteristic elaboration of the concrete mechanisms of excitation, sustention and damping of high-frequency oscillation in HTR of energy transformers of various designation;

3. electric-and-physical data are highly informative and rich in a diagnostic content, and it is exactly these qualities that substantiate expedience and efficiency of their application for monitoring and control of characteristics of both in-chamber processes and energy transformers (including engines) of different designation, as a whole.

Let us identify the key trends we are in a position to analyze with the help of our own methods. They are the following:

1. Determination of the fuel burn-up curve. This curve is one of the principal characteristics for the engine of any type. Its run determines to a great degree economic efficiency of the engine and its environmental friendliness.

2. Obtaining frequency response of combustion process in HTR. Their characteristic measurement is associated with analysis of engine operation stability and features of physical-and-chemical processes taking place throughout combustion.

3. Computation and experimental determination of HTR walls electrification caused by development of electric-and-physical processes in combustion yield plasma. These phenomena are connected with undesirable appearance of potential (up to $\pm$ 400 B) on the engine's body.

4. Development of engine's safety and emergency shut-down systems based on analysis of high-frequency characteristics of the processes taking place in HTR.

Measurement and application of electric-and-physical properties of combustion yields plasma are justly regarded as fundamental results. Clear-cut inter-connection has been established between electric-and-physical properties (potential, conductivity) and passage of shock and acoustic waves through combustion yields plasma. Investigation of these regularities

carried out with the help of up-to-date experimental methods opens broad opportunities of practical application in many spheres.

In the course of works, noise reduction techniques for the engine have been suggested. The most appealing one from perspective point of view is associated with application of sound-absorbing metal possessing unique acoustic properties and preserving at the same time all common features inherent in the standard steel. Subsequent experiments will show which engine parts are subject to modification.

All executed works have been aimed in perspective at enhancing safety and flight control, reduction of noise and negative impact on the environment. The strategic objective of our efforts is design and development of techniques and devices which, upon their implementation in the aeronautical and outer space engineering will raise dependability and environmental friendliness of aerospace systems onto qualitatively new level.
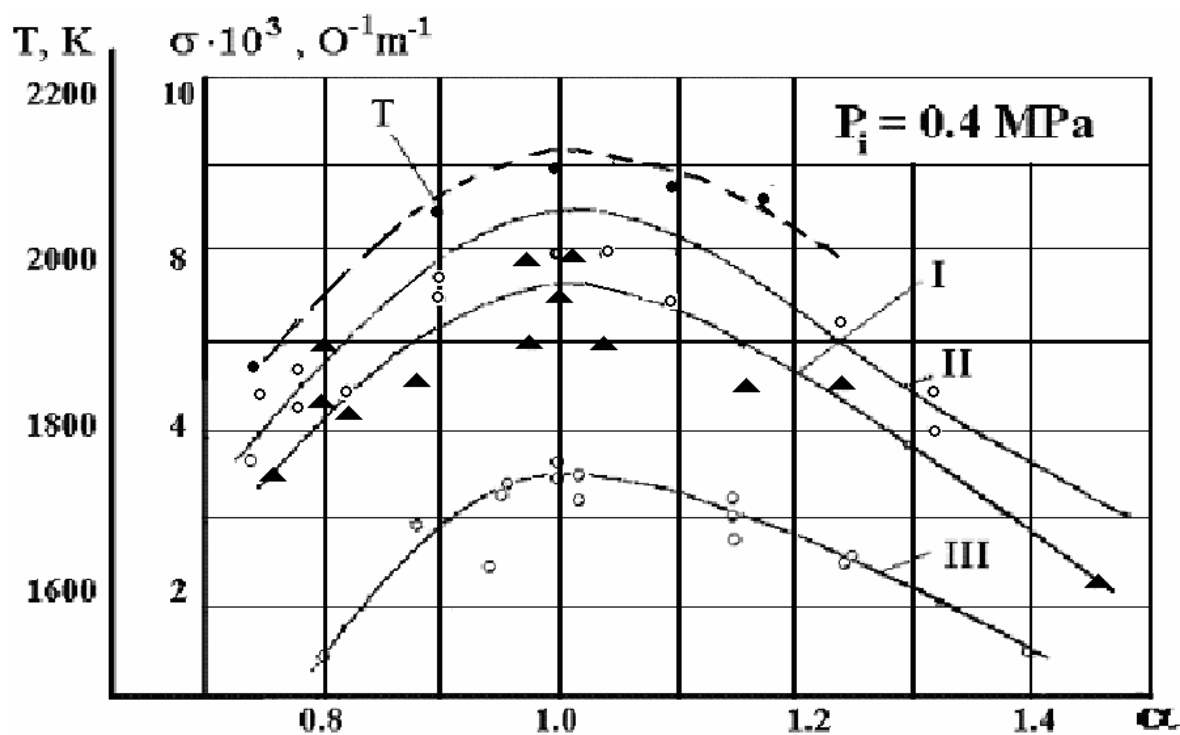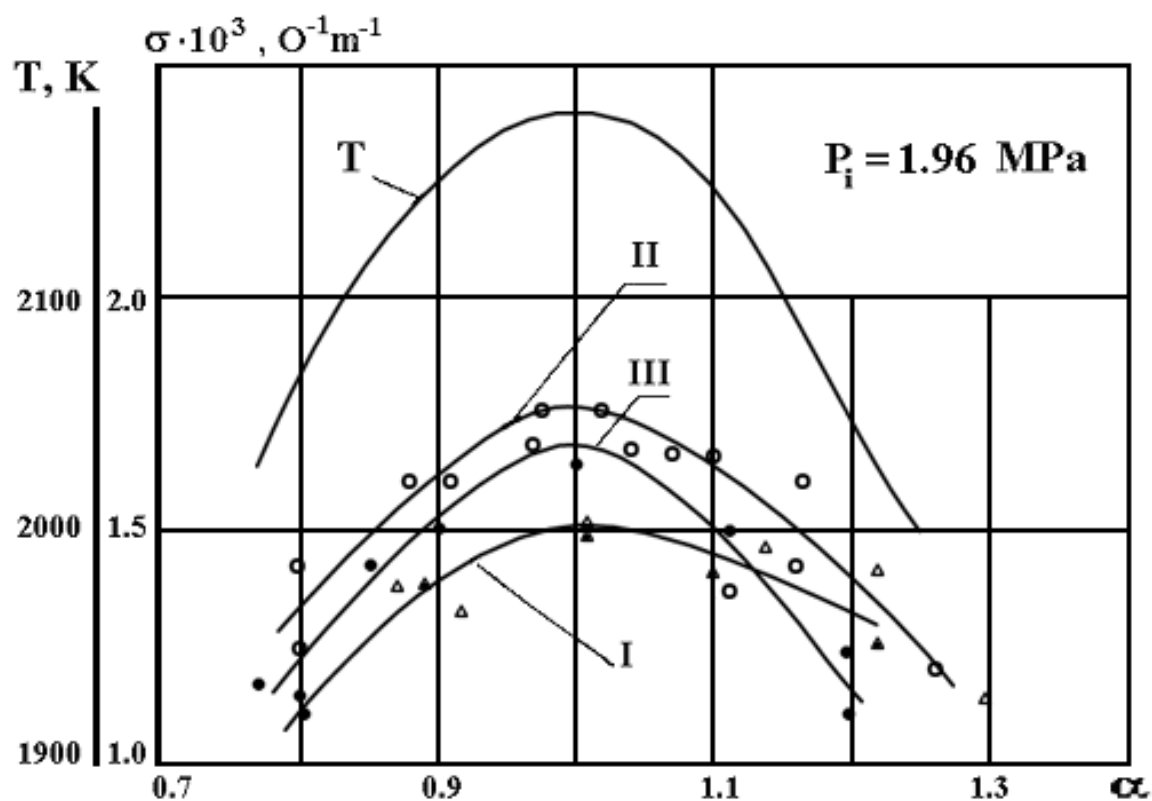
Fig. 1 Electric conductivity and temperature (dotted curve) as a function of oxidation excess coefficient at kerosene combustion in air. Optimal value of oxidation excess coefficient is ~1, and pressure - 0.4 MPa. The measurements have been taken in three successive HTR channel cross-sections.



Fig. 2.Electric conductivity and temperature (dotted curve) as a function of oxidation excess coefficient at kerosene combustion in air. Optimal value of oxidation excess coefficient ~1, and pressure - 1.96 MPa. The measurements have been taken in three successive HTR channel cross-sections.
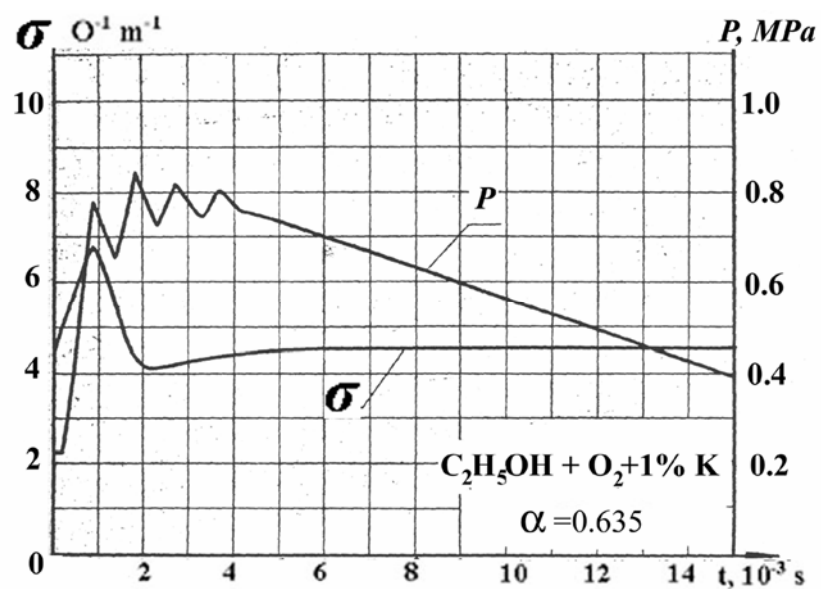
Fig.3. Reaction of plasma conductivity σ on shock wave appearance – variation of pressure **P**